ON HEAT TRANSFER IN NUCLEATE BOILING (I)

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ABSTRACT. Representative data of heat transfer coefficient for di-ethyl ether (B.P. 34.5°C) boiling on submerged horizontal tubes of copper, nickel and an alloy of Cu, Ni and Zinc, 3/16″ in external diameter heated by enclosed electrical heaters have been obtained for a flux range upto 55000 Btu/hr. sq.ft. Data were obtained both for the commercial variety and purified liquid. The purity of the liquid is specified by data taken on electrical conductivity. To reduce the hysteresis effect, the liquid was stirred by a magnetic stirrer. The rotor speed was maintained at 650 r.p.m. and was determined by a stroboscope. After continued boiling the boiling curves showed to be almost straight lines for the heat flux range from 10,000 to 55,000 Btu/hr. sq.ft. The coefficient was found to be greater for the impure liquid than for the purified liquid at each heat flux.

INTRODUCTION

Heat transfer between a submerged solid surface and a liquid boiling on it has been the subject of study of many investigators during recent years. A stimulating account of the art of boiling and the advancement towards the understanding of the boiling phenomena has been given by Drew and Mueller (1937), and J. W. Westwater (1956). Most of the boiling curves published show some hysteresis effect in the steady nucleate region and a very pronounced hysteresis effect at the threshold of nucleate boiling (Sinha, 1955). Regarding the effect of agitation on nucleate boiling Austin (1902) showed that stirring produced some increase in the heat transfer coefficient at moderate heat flux. Drew and Mueller (1937) confirmed Austin. Feeble agitation, on the other hand, has the advantage of decreasing the hysteresis effect without affecting the heat transfer coefficient at higher heat flux when the agitation produced by the coloumns of rising vapour bubbles is quite high. While reporting on heat transfer coefficient very little has been said by any worker about the purity of the liquid samples tried, though much has been said about the conditions of the heater surfaces. A point of interest in the problem should be to investigate how the purity condition of the liquid behaves in heat transfer and this is reported in the present work.

EXPERIMENTAL APPARATUS

(1) *Construction of the heater*

Very thin walled (.004″), 3/16″ diameter metal tubes were taken. Approximate lengths of the tubes were 7 cms. Glass insulated nicrome wires of gauge

No. 30 (dia. 0.026 cm) were placed within the tubes and were electrically heated. The technique employed for sealing the ends of the heater tube is shown in the schematic diagram shown in Fig. (1).

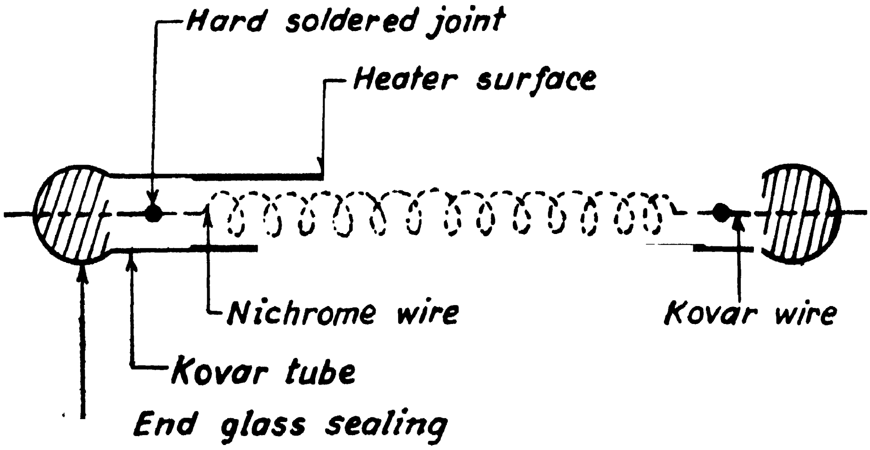

Fig. 1. Constructional details of the heaters.

The nichrome wire is hard soldered to a 'Kovar' wire. The 'Kovar' wire passes through a 'Kovar' tube of slightly smaller diameter than that of the heater tube. The 'Kovar' tube is soft soldered to the heater tube. Finally, the end is sealed with glass. The 'Kovar' wires serve as lead-in wires.

(2) *Purification of the liquid* :

The chief impurities in commercial ether (Sp. gr. 0.72) are water, ethyl alcohol, trazes of aldehyde, and in samples which have been exposed to the air and light for sometime or has been stored for a long time, ethyl peroxide. The ether was taken in a big separating funnel and was shaken vigourously with a saturated soltuion of ferrous sulphate. The ether was drained off and sufficient quantity of anhydrous calcium chloride was added to it. The mixture was allowed to stand for 24 hours with occasional shaking. Both the water and alcohol present were thus largely absorbed. The sample was then distilled doubly over phosphorus pentoxide. Sodium wires were inserted in the distilled ether to remove the last traces of moisture. Before use this ether was filtered. The purity of the sample was tested by experimentally studying its electrical conductivity.

(3) *Stirring* :

The liquid was taken in a dewar and was stirred with the help of a magnetic stirrer. The method of magnetic stirring was adopted because it offered least contamination and also offered no path for heat leakage. For convenience of steady operation the conventional permanent magnet type of stirrer was modified to an electromagnet type of stirrer. The stirring element was a glass bead, cylindrical in shape, of length 2.8 cm and diameter 0.8 cm., in which was embedded a magnetic core. The r.p.m. of the stirrer could be regulated by the simultaneous control of the speed and strength of the magnetic field. The r.p.m. was measured by a stroboscope (ORION-EMG, Type 2371/B)

(4) *Measurements*

Wedge shaped contact electrodes made of the same metals as those of the heater tubes placed at a fixed distance apart on an ebonite former were used to measure the p.d. between the contact points for a constant current sent through the tube material supplied from a battery which was continuously kept at constant e.m.f. by a battery charger. The resistance of the tube material was obtained by comparison with a standard low resistance. The temperature of the tube surface at each heat flux was evaluated from the resistance so determined (Sinha, 1955). The liquid temperature (bulk) was measured by 3 welded type single junction thermo-couples (copper-constantan). The p.d.'s were measured by a standardised Diesselhorst thermoelectric free potentiometer capable of reading upto 0.1 μv. The actual measurements were taken down to 1μv.

Experimental procedure

The tube surfaces were very thoroughly cleansed by successive washing with acetone, benzene, carbon tetrachloride and finally with ether. Care was taken to avoid any contamination from grease. The liquid was charged into the dewar. The measuring current was then set in and the whole assembly was allowed to stand for sometime before the heating current was switched on. Theheating current was increased in steps of 0.2 amp. and the corresponding p.d. between the electrodes were noted. After reaching a suitable maximum value the heating current was decreased in steps of 0.2 amp to test for hysteresis effect. The bulk liquid temperature was also measured in each step by means of three thermocouples inserted into the liquid at different depths. Between successive runs, the whole system was allowed to stand idle for about one hour. Several such runs were taken for each tube to test for reproducibility of results. Before performing a run the standardisation of the potentiometer was checked up each time.

RESULTS

Experiments were performed with three copper tubes, two tubes of an alloy of Cu-nickel Zinc (5.88% Cu, 16.48% Ni and 77.50% Zinc) and one tube of Nickel supplied by Messrs. Johnson Matthey and Co. Ltd., London. Commercial ether (labelled, solvent) and the same after purification were used. Five runs were performed for each heater-liquid combination.

The values of Δt (temp. difference between the heater surface and bulk liquid) and h(heat transfer coefficient) as obtained in the present work for the different heaters, at a fixed heat flux viz. 45,000 Btu/hr.sq.ft. is shown in the table below. The Graphs in Fig. Nos. 2, 3, 4 show the variation of heat flux with Δt and h vs Δt in the range of heat flux from 10,000 to 55,000 Btu/hr. sq.ft.

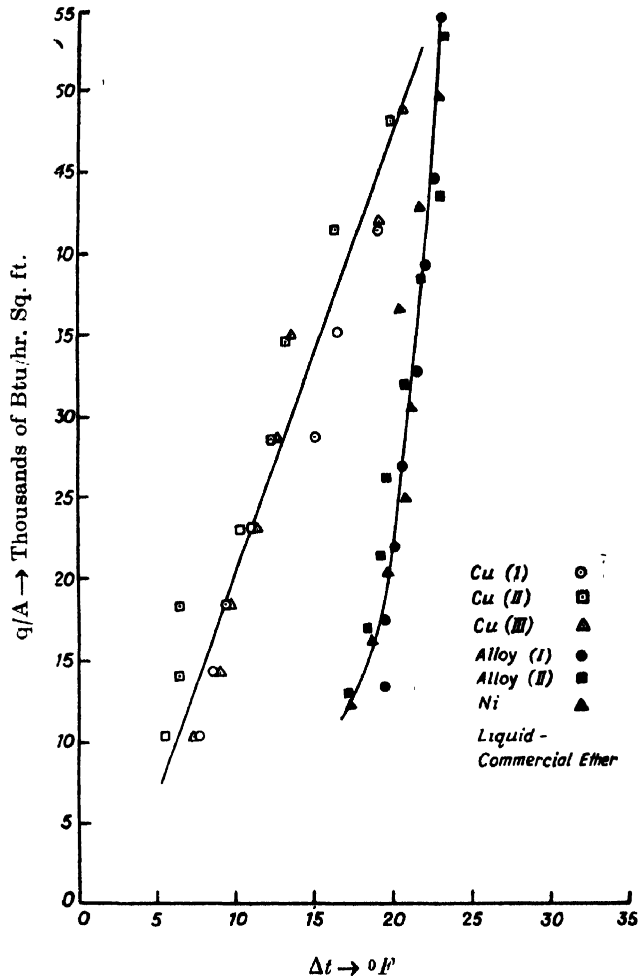

Fig. 2. q/A vs. Δt curves for commercial ether

TABLE I

Liquid :		Heater material	Heat flux Btu/hr. sq.ft.	Δt °F	h. Btu/hr. sq.ft.
Ether (Ordinary)	(*i*)	Cu.	45,000	19	2365
	(*ii*)	Cu-Ni-Zn. alloy and Nickel	,,	22	2045
Ether (Purified)	(*i*)	Cu.	,,	21.25	2120
	(*ii*)	Cu-Ni-Zn. alloy and Nickel	,,	24.75	1820

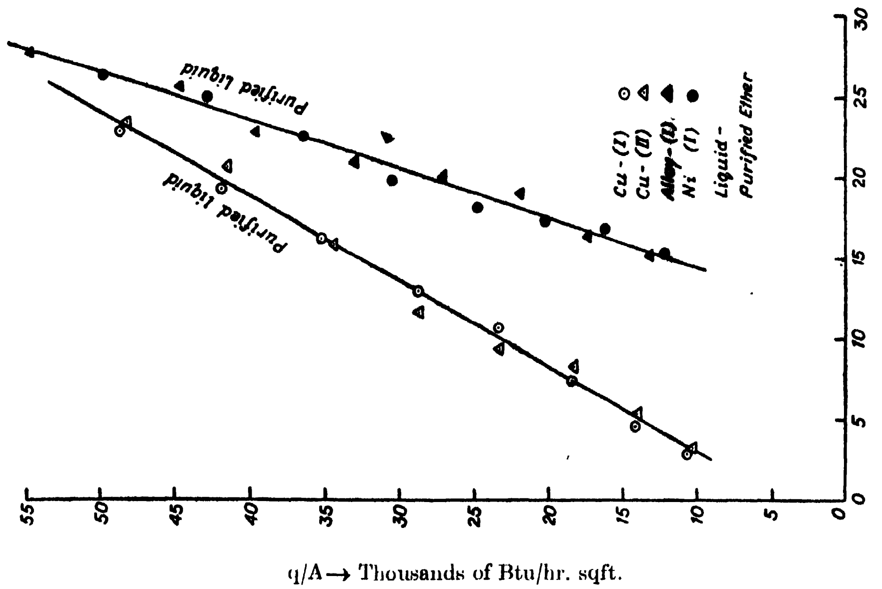

Fig. 3. q/A vs. Δt curves for pure ether.

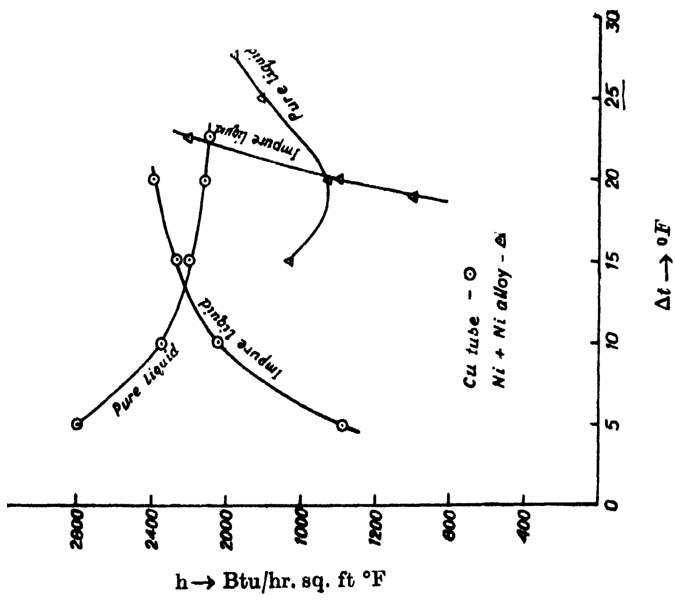

Fig. 4. h vs Δt curves.

CONCLUSION

(1) The variation of slopes in q/A vs Δt curves between the ordinary liquid and the liquid, when purified, is not much significant.

(2) For the same tube and the same heat flux, the heat transfer coefficient decreased from impure to pure liquid.

(3) The $h \sim \Delta t$ curves did not follow similar patterns.

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